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FINAL REPORT

NASA Grant NAG2-208

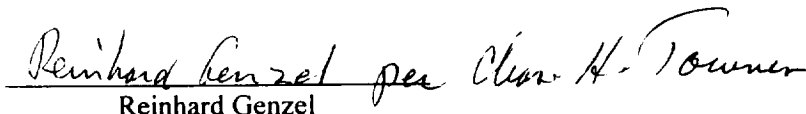
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**Spectroscopic Observations of the Infrared Lines Normally Obscured
by Atmospheric Absorption**

Submitted: January 7, 1997



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510/642-1128



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Final Report NASA grant NAG2-208

This grant, begun November 1, 1982, represents continuation of the development of far infrared instrumentation and high altitude observations which had begun almost a decade earlier. By 1982 we had good instrumentation, but it was to be followed by another decade of further development in obtaining higher sensitivity and high spectral resolution. The initial proposal stated that "our general program is to detect and measure fine structure lines of ions in the ground state and molecular rotational or ro-vibrational transitions in a variety of astronomical objects. The primary emphasis of our program is on interstellar gas in order to understand the composition, state, and dynamics of both ionized and un-ionized regions." We have been very fortunate to realize such a program over the last 14 years using the Kuiper Astronomical Observatory and several instrumental innovations and equipment upgradings. This has allowed us to obtain a wide range of information on galaxies, on the center of our own galaxy, and on especially interesting localized regions such as the clouds and ionized gas in Orion. Work has included study of the wide range of conditions of interstellar gas, from highly ionized material to atomic gas, to warm molecular gas, and to cool molecular material. It has also included a wide range of dynamics from systematic motions about the center of our own galaxy and in other galaxies to turbulence, shock waves, and magnetically controlled motions. We believe that this grant and the work associated with it have been extremely rewarding.

When we began work under this grant in 1982, we were using a single sensitive semiconductor detector and with our Fabry-Perot spectrometer measuring the spectra of individual points in various patches of galactic gas. Soon thereafter, we were able to use a linear array of 3 detectors so that we multiplied the amount of information by a factor of 3. This was particularly important for mapping. By 1988, a still newer version of this type of instrumentation had been built with a 5×5 array of detectors, giving us measurements of 25 positions all at one time. In addition, this new system could use either two

or three Fabry-Perots in series, allowing a range of spectral resolutions including extremely high resolution. These improvements very much accelerated and enhanced measurements of the type which were important for the purposes stated above.

The productivity and results of our work in the KAO can be immediately seen from the list of publications resulting from this work, which is attached. In addition to these publications, various members of our team have written theses and given many talks which resulted from this work.

We have enjoyed collaborating with a number of scientists from other institutions who have used our equipment. We have also had an excellent team of individuals working with us, including a number of postdocs and students who have now moved on into further fruitful work, many in this general field of research. In the latter part of the period of this grant, the work has been a collaboration between scientists at Berkeley and those at the Max Planck Institute in Garching under the direction of Reinhard Genzel, who began this type of work as a postdoc here at Berkeley and then became a faculty member. Many German students have also obtained their Ph.D. degrees and written theses in connection with this work. Table 1 lists the more important postdoctoral fellows who worked with us on this project in Berkeley, a few who worked in Garching, and also the American students who obtained their Ph.D. degrees in connection with research under this grant. This is a talented group of people who continue to serve the U.S. and the world of science in important ways.

We are grateful to NASA for its support of this work, and particularly grateful to the many individuals associated with NASA Ames who have been extremely helpful and cooperative in working with us and in operating the Kuiper Astronomical Observatory. They have been very skillful and effective.

Table 1

Postdoctoral Fellows

Michael Crawford
Norbert Geis

Reinhard Genzel

David Jaffe
Sue Madden

Albrecht Poglitsch

Gordon Stacey
John Storey
Juergen Stutski

Present Position

Scientific Staff, DuPont Company
Scientific Staff, Max Planck Institute for Exterrestrial
Physics
Director of the Max Planck Institute for Exterrestrial
Physics
Faculty, University of Texas
Scientific Staff, Southern European Observatory
Saclay, France
Scientific Staff, Max Planck Institute for Exterrestrial
Physics
Faculty, Cornell University
Faculty, University of New South Wales
Faculty, Univeristy of Cologne, Germany

Students

Sara Beck
Samuel Gasster
Lawrence Greenberg
Andrew Harris
John Lacy
John Lugten
Daniel Watson

Faculty, University of Tel Aviv
The Aerospace Corporation
The Aerospace Corporation
Faculty, University of Massachusetts
Faculty, University of Texas
Scientific Staff, University of California at Berkeley
Faculty, Rochester University

1983

- “Detection of Interstellar NH_3 the Far-Infrared: Warm and Dense Gas in Orion-KL,” C.H. Townes, R. Genzel, D. Watson, and J. Storey, *Ap. J. Lett.* **269**, L11 (1983).
- “A Far-Infrared Study of the N/O Abundance Ratio in Galactic HII Regions,” D. Lester, H.L. Dinerstein, M. Werner, D. Watson, and R. Genzel, *Ap. J.* **271**, 618 (1983).

1984

- “Far-Infrared Spectroscopy of the Galactic Center: Neutral and Ionized Gas in the Central 10 Parsecs of the Galaxy,” R. Genzel, D.M. Watson, C.H. Townes, H.L. Dinerstein, D. Hollenbach, D. Lester, M. Werner, and J.W.V. Storey, *Ap. J.* **276**, 551 (1984).
- “Detection of Far-Infrared [OI] and [O III] Emission from the Galaxy M82,” D.M. Watson, R. Genzel, C.H. Townes, M.W. Werner, and J.W.V. Storey, *Ap. J.* **279**, L1 (1984).
- “Detection of Shocked Atomic Gas in the Kleinmann-Low Nebula,” M.W. Werner, M.K. Crawford, R. Genzel, D.J. Hollenbach, C.H. Townes, and D.M. Watson, *Ap. J.* **28**, L81 (1984).

1985

- “Far-Infrared Spectroscopy of Galaxies: The $158\ \mu\text{m}$ C^+ Line and the Energy Balance of Molecular Clouds,” M.K. Crawford, R. Genzel, C.H. Townes, and D.M. Watson, *Ap. J.* **291**, 755 (1985).
- “Mass Distribution in the Galactic Center,” M.K. Crawford, R. Genzel, A.I. Harris, D.T. Jaffe, J.H. Lacy, J.B. Lugten, E. Serabyn, and C.H. Townes, *Nature* **315**, 467 (1985).
- “The Neutral-Gas Disk Around the Galactic Center,” R. Genzel, D.M. Watson, M.K. Crawford, and C.H. Townes, *Ap. J.* **297**, 766 (1985).
- “Far-Infrared Emission Lines of CO and OH in the Orion-KL Molecular Shock,” D.M. Watson, R. Genzel, C.H. Townes, and J.W.V. Storey, *Ap. J.* **298**, 316 (1985).
- “Far-Infrared and Submillimeter Astronomical Spectroscopy,” R. Genzel and G.J. Stacey, *Mittg. Astron. Ges.* **63**, 215 (1985).

1986

- “Excitation Gradient of the Molecular Gas in the Sgr A Circum-Nuclear Ring,” J.B. Lugten, G.J. Stacey, A.I. Harris, R. Genzel, and C.H. Townes, *The Galactic Center, AIP Conference Proceedings*, 155, D.C. Baker (ed.), (1986).
- “Mapping of C^+ Far-Infrared Emission in the Inner Galaxy,” J.B. Lugten, R. Genzel, M.K. Crawford, and C.H. Townes, *The Galactic Center, AIP Conference Proceedings*, 155, D.C. Baker (ed.), (1986).
- “[CII] $158\ \mu\text{m}$ Mapping in Sgr A: Rotation Curve and Mass Distribution in the Center of the Galaxy,” J.B. Lugten, R. Genzel, M.K. Crawford, and C.H. Townes, *Ap. J.* **306**, 691 (1986).

“Detection of OH from Comet Halley in the Far-Infrared,” G.J. Stacey, J.B. Lugten, and R. Genzel, *Proc. ESLAB Symp.* (Heidelberg), B. Battrock, E.J. Rolfe, and R. Reinhard R. (eds.), *ESA-SP 250*, 1, 369 (1986).

“Observations of Far-Infrared Line Profiles in the Orion-KL Region,” M.K. Crawford, J.B. Lugten, W. Fitelson, R. Genzel, and G. Melnick, *Ap. J. Lett.* **303**, L57 (1986).

“The Interstellar Medium in the Central 1 kicoparsec of M82,” J.B. Lugten, D.M. Watson, M.K. Crawford, and R. Genzel, *Ap. J. Lett.* **311**, L51 (1986).

1987

“Physical Conditions, Dynamics and Mass Distribution in the Center of the Galaxy,” R. Genzel and C.H. Townes, *Ann. Rev. Astron. Astrophys.* **25**, 377 (1987).

“The Interstellar Medium in Star Burst Galaxies,” R. Genzel, J.B. Lugten, M.K. Crawford, and D.M. Watson, *Proc. ESLAB Symp.* (Heidelberg), B. Battrock, E.J. Rolfe, and R. Reinhard (eds.), *ESA-SP 250*, 1, 614 (1987).

“Warm Dense Gas in Luminous Protostellar Region: A Submillimeter and Far-Infrared CO Line Study,” D.T. Jaffe, A.I. Harris, and R. Genzel, *Ap. J.* **3**, 231 (1987).

“Far-Infrared Measurements of N/O in HII Regions: Evidence for Enhanced CN Process Nucleosynthesis in the Inner Galaxy,” D.F. Lester, H.L. Dinerstein, M.W. Werner, D.M. Watson, R. Genzel, and J.W.V. Storey, *Ap. J.* **320**, 573 (1987).

“Detection of Interstellar CH in the Far-Infrared,” G.J. Stacey, J.B. Lugten, and R. Genzel, *Ap. J.* **313**, 859 (1987).

“Sources of Rotationally Excited Far-Infrared OH Emission in Orion-KL,” G. Melnick, R. Genzel, and J.B. Lugten, *Ap. J.* **321**, 530 (1987).

“Submillimeter and Far-Infrared Spectroscopy of M17 and S106: UV-Heated, Quiescent Molecular Gas,” A.L. Harris, J. Stutzki, R. Genzel, J.B. Lugten, G.J. Stacey, and D.T. Jaffe, *Ap. J. Lett.* **322**, L49. (1987).

“Detection of OH Rotational Emission from Comet P/Halley in the Far-Infrared,” G.J. Stacey, J.B. Lugten, and R. Genzel, *Astr. & Ap.* **187**, No.1/2, 451 (1987).

1988

“Foreign-gas Collision Broadening of the Far-infrared Spectrum of Water Vapor,” Samuel D. Gasster, Charles H. Townes, David Goorvitch, and Francisco P.J. Valero, *Journal of the Optical Society of America*, **5**, 593 (1988).

“The Galactic Center,” C.H. Townes, in *Evolutionary Phenomena in Galaxies*, University of Cambridge Press (1988).

- “Submillimeter and Far-infrared Observations of Photodissociation Regions: A Detailed Study of M17 SW,” A.I. Harris, J. Stutzki, J. Herman, R. Genzel, D.T. Jaffe, J.B. Lugten, G.J. Stacey, and C.H. Townes, *Molecular Clouds in the Milky Way and External Galaxies*, J. Young (ed.), Springer-Verlag (1988).
- “The Galactic Nucleus at Millimeter, Submillimeter and Far-Infrared Wave-lengths,” R. Genzel, *Proc. of Stirling Summer School on Millimetre and Submillimetre Astronomy*, R.D. Wolstencroft and B. Burton (eds.), Kluwer (Dordrecht), 223-248 (1988).
- “Detection of Far-Infrared ^{13}CO Line Emission,” R. Genzel, A. Poglitsch, and G.J. Stacey, *Ap.J. Lett.* **333**, L59.(1988).
- “Submillimeter and Far-Infrared Line Observations of M17SW: A Clumpy Molecular Cloud Penetrated by UV Radiation,” J. Stutzki, G.J. Stacey, R. Genzel, A.L. Harris, D.T. Jaffe, and J.B. Lugten, *Ap.J.* **332**, 379 (1988).
- “Far-Infrared, Rotationally Excited OH Emission in Orion-KL,” G.J. Melnick, R. Genzel, A. Poglitsch, G.J. Stacey, and J.B. Lugten J.B., *Proc. 2nd Haystack Observatory Meeting, “Interstellar Matter,”* J. M. Moran and P.T. P. Ho, (eds.), (Gordon and Breach), p.187 (1988).

1989

- “The Galactic Center - Introductory Review: Outstanding Puzzles and Challenges,” C.H. Townes, in the *Proceedings of the Galactic Center, IAU Symposium No. 136*, M. Morris and J.E. Beckman (eds.), *The Center of the Galaxy*, 1, IAU (1989).
- “158 μm [CII] Mapping of the Galactic Center Molecular Clouds,” R. Genzel, G.J. Stacey, C.H. Townes, A. Poglitsch, and N. Geis, *IAU Symposium No. 136: The Galactic Center*, M. Morris (ed.), 151 (1989).
- “[CII] Line Emission from Spiral Galaxies,” G.J. Stacey, R. Genzel, J.B. Lugten, and C.H. Townes, *The Physics and Chemistry of Interstellar Molecular Clouds*, G. Winnewisser and J.T. Armstrong (eds.), Springer-Verlag (1989)
- “Shocked Carbon Monoxide in G333.6-0.2,” J.M.V. Storey, J.I. Harnett, J.B. Lugten, M.K. Crawford, G.J. Stacey, D.M. Watson, and R. Genzel, *MNRAS* **237**, 1001 (1989).

1990

- “Atmospheric Transmission in the Far-infrared at the South Pole and Astronomical Applications,” C.H. Townes and G. Melnick, *Publications of the Astronomical Society of the Pacific* **102**, 387 (1990).
- “The Galactic Center,” C.H. Townes, *Proceedings of Astrophysics and Infrared Arrays*, Tucson, AZ, February 1990.
- “What’s Happening in the Center of Our Galaxy?,” C.H. Townes and R. Genzel, *Scientific American* **262**, 46, April 1990.

- "Far-infrared, Submillimeter, and Millimeter Spectroscopy of the Galactic Center: Radio Arc and + 20/ + 50 kilometer per second Clouds," R. Genzel, G.J. Stacey, A.I. Harris, C.H. Townes, N. Geis, U.U. Graf, A. Poglitsch and J. Stutzki, *Ap. J.* **356**, 160 (1990).
- "Imaging Triple-Fabry-Perot Spectrometer for Far-infrared Astronomy," A. Poglitsch, N. Geis, M. Haggerty, R. Genzel, G. Stacey, and C.H. Townes, *Submillimeter and Millimeter Wave Astronomy*, G.D. Watt and A.S. Webster (eds.), Kluwer Academic **67** (1990).
- "158 μm [CII] Line Emission from Galaxies," G.J. Stacey, R. Genzel, J.B. Lugten, and C.H. Townes, *Submillimeter and Millimeter Wave Astronomy*, G.D. Watt and A.S. Webster (eds.), Kluwer Academic **125** (1990).
- "The MPE/UCB Far-infrared Imaging Fabry-Perot Interferometer (FIFI)," A. Poglitsch, J.W. Beeman, N. Geis, R. Genzel, M. Haggerty, E.E. Haller, J. Jackson, M. Rumitz, G.J. Stacey, and C.H. Townes, *Proc. 29th International Astrophys. Colloquium, ESA SP-314* (December 1990).
- "The Galactic Centre in the Submillimetre and Far-Infrared Wavelengths: A Progress Report," R. Genzel *Proc. 29th Liège Intern. Astrophysical Colloquium*, "From Ground-Based to Space-Borne Submm Astronomy," B.H. Kaldeich (ed.), *ESA-SP 314*, 27 (1990).
- "Further Observations of Rotationally Excited Far-Infrared OH and ^{18}OH Emission in Orion-KL: Tighter Constraints on the Nature of the Emission Region," G.J. Melnick, G.J. Stacey, R. Genzel, J.B. Lugten, and A. Poglitsch, *Ap.J.* **348**, 1 (1990).
- "Physical Conditions in Molecular Clouds Derived from Sub-mm and Far-Infrared Spectroscopic Observations," J. Stutzki, G.J. Stacey, R. Genzel, U.U. Graf, A.I. Harris, D.T. Jaffe, J.B. Lugten, and A. Poglitsch, *Intern. Symp. on Submillimetre and Millimetre Astronomy*, Kona (Hawaii), A.S. Webster (ed.), Kluwer (Dordrecht), p. 269-273 (1990).
- "Detection of Far-Infrared ^{13}CO Line Emission," A. Poglitsch, R. Genzel, and G.J. Stacey, *Intern. Symp. on Submillimetre and Millimetre Astronomy*, Kona (Hawaii), A.S. Webster (ed.) Kluwer (Dordrecht), p. 261 (1990).
- "Hot Quiescent Gas in Photodissociation Regions CO and C^+ Observations of NGC 2023," D.T. Jaffe, J.E. Howe, R. Genzel, A.I. Harris, J. Stutzki, and G.J. Stacey, *Intern. Symp. on Submillimetre and Millimetre Astronomy*, p.127-128 (1990).
- "Extensive C^+ 158 μm Mapping of W3 and NGC 1977," J.E. Howe, N. Geis, R. Genzel, D.T. Jaffe, A. Poglitsch, and G.J. Stacey, *Intern. Symp. on Submillimetre and Millimetre Astronomy*, p. 285 (1990).

1991

- "The 158 μm [CII] Line: A Measure of Global Star Formation Activity in Galaxies," G.J. Stacey, N. Geis, R. Genzel, J.B. Lugten, A. Poglitsch, A. Sternberg, and C.H. Townes, *Ap. J.* **373**, 423 (1991).
- "[CII] 158 μm Mapping of Spiral Galaxies," G.J. Stacey, N. Geis, R. Genzel, J.M. Jackson, A. Poglitsch, and C.H. Townes, *Proceedings of the 29th Liège International Astrophysical Colloquium: From Ground-based to Space-borne Sub-mm Astronomy*, B.H. Kaldeich (ed.), *ESA, SP-314*, 85 (1991).

“A Survey of the 158 μm [CII] Fine-structure Line in the Central 50 pc of the Galaxy,” A. Poglitsch, G.J. Stacey, N. Geis, M. Haggerty, J. Jackson, M. Rumitz, R. Genzel, and C.H. Townes, *Ap. J. Lett.* **374**, L33 (1991).

“The Optical Depth of the 158 μm [^{12}C II] Line: Detection of the $F = 1 \rightarrow 0$ [^{13}C II] Hyperfine-structure Component,” G.J. Stacey, C.H. Townes, A. Poglitsch, S.C. Madden, J.M. Jackson, F. Herrmann, R. Genzel, and N. Geis, *Ap. J. Lett.* **382**, L37 (1991).

“The MPE/UCB Far-infrared Imaging Fabry-Perot Interferometer (FIFI),” A. Poglitsch, J.W. Beeman, N. Geis, R. Genzel, M. Haggerty, E.E. Haller, J. Jackson, M. Rumitz, G.J. Stacey, and C.H. Townes, *Internat. J. Infrared Millimeter Waves*, **12**, 859 (1991).

“Parsec-Scale Penetration of UV into Molecular Clouds: [CII] 158 μm Mapping of W3, NGC 1977, and NGC 2023,” J.E. Howe, D.T. Jaffe, R. Genzel, and G.J. Stacey, *Ap.J.* **373**, 158 (1991).

1992

“Heating of HII Regions with Application to the Galactic Center,” Philip R. Maloney and David J. Hollenbach, and C.H. Townes, *Ap. J.* **401**, 559 (1992).

1993

“Neutral Gas in the Central 2 Parsecs of the Galaxy,” J.M. Jackson, N. Geis, R. Genzel, A.I. Harris, S. Madden, A. Poglitsch, G. Stacey, and C.H. Townes, *Ap. J.* **402**, 123 (1993).

“158 micron [C II] Mapping of the Orion Molecular Cloud,” G.J. Stacey, D.T. Jaffe, N. Geis, R. Genzel, A.I. Harris, A. Poglitsch, and J. Stutzki, *Ap. J.* **404**, 219 (1993).

“158 micron [C II] Mapping of NGC 6946: Probing the Atomic Medium,” S.C. Madden, N. Geis, R. Genzel, F. Herrmann, J.M. Jackson, A. Poglitsch, G.J. Stacey, and C.H. Townes, *Ap. J.* **407**, 579 (1993).

“Introduction: Radio and IR Studies of Molecular Clouds,” C.H. Townes, *Conference on Molecular Clouds*, Ringberg Castle, Tegernsee, Germany, April 13-15, 1993.

“158 μm [C II] Mapping of Galaxies: Probing the Atomic Medium,” S.C. Madden, N. Geis, R. Genzel, F. Herrmann, J. Jackson, A. Poglitsch, G.J. Stacey, and C.H. Townes, *The Evolution of Galaxies and Their Environment*, Proceedings of the Third Teton Summer School in Astrophysics, July 5-10, 1992. *NASA Conf. Publ.* **3190**, 185 (1993).

“Far-Infrared Line Images of Dwarf Galaxies,” A. Poglitsch, N. Geis, R. Genzel, F. Herrmann, S.C. Madden, G.J. Stacey, and C.H. Townes, *The Evolution of Galaxies and Their Environment*, Proceedings of the Third Teton Summer School in Astrophysics, July 5-10, 1992. *NASA Conf. Publ.* **3190**, 187 (1993).

“CO Lines Toward NGC 2024 and Other Star Forming Regions: A Closer Look at the Warm Gas Component”, U.U. Graf, A. Eckart, R. Genzel, A.I. Harris, A. Poglitsch, A.P.G. Russell, and J. Stutzki, *Ap.J.* **405**, 249.(1993).

1994

- “Evidence for a Massive Black Hole in the Center of Our Galaxy,” C.H. Townes, in *Quantum Coherence and Reality*, J.S. Anandan and J.L. Safko (eds.), *Proc. of Int’l. Conf. on Fund. Aspects of Quant. Theory*, World Scientific Publishing (1994).
- “The nucleus of our Galaxy,” R. Genzel, D. Hollenbach, and C.H. Townes, *Rep. Prog. Phys.* **57**, 417 (1994).
- “The Nuclei of Normal Galaxies: Lessons from the Galactic Center - A Brief Summary,” C.H. Townes, *The Nuclei of Normal Galaxies: Lessons from the Galactic Center*, R. Genzel and A.I. Harris (eds.), **455**, 463, Kluwer Academic Publishers (1994).
- “Properties and Evolution of the Central Stellar Cluster,” R. Genzel, D.J. Hollenbach, C.H. Townes, A. Eckart, A. Krabbe, D. Lutz, and F. Najarro. *The Nuclei of Normal Galaxies: Lessons from the Galactic Center*, R. Genzel and A.I. Harris (eds.), **445**, 327, Kluwer Academic Publishers (1994).
- “Spectroscopy of the Galactic Center Arches Region: Evidence for Massive Star Formation,” A.I. Harris, T. Krenz, R. Genzel, A. Krabbe, D. Lutz, A. Poglitsch, C.H. Townes, and T.R. Geballe, *The Nuclei of Normal Galaxies: Lessons from the Galactic Center*, R. Genzel and A.I. Harris (eds.), **445**, p. 223, Kluwer Academic Publishers (1994).
- “Far-infrared studies of the Orion Nebula,” F. Herrmann, N. Geis, R. Genzel, S.C. Madden, A. Poglitsch, G.J. Stacey, and C.H. Townes, *Infrared Phys. Technol.* **35**, No. 2/3, 161 (1994).
- “The interstellar medium of galaxies as seen through images of the 158 μm [CII] line,” S.C. Madden, N. Geis, R. Genzel, F. Herrmann, A. Poglitsch, G.J. Stacey, and C.H. Townes, *Infrared Phys. Technol.* **35**, No. 2/3, 311 (1994).
- “Infrared observations of the center of the galaxy,” A. Poglitsch, N. Geis, R. Genzel, A.I. Harris, J.M. Jackson, T. Krenz, S.C. Madden, G.J. Stacey, and C.H. Townes, *Infrared Phys. Technol.* **35**, No. 2/3, 419 (1994).
- “Far infrared spectra of galaxies,” C.H. Townes and N. Geis, *Proc. of the SPIE* **2211**, p. 14 (1994).
- “Far-infrared observations of the center of the galaxy,” A. Poglitsch, N. Geis, R. Genzel, F. Herrmann, J.M. Jackson, S.C. Madden, T. Nikola, G.J. Stacey, and C.H. Townes, *The Nuclei of Normal Galaxies: Lessons from the Galactic Center*, R. Genzel and A.I. Harris (eds.) **445**, p. 239, Kluwer (1994).

1995

- “FIFI - the MPE Garching/UC Berkeley Far-Infrared Imaging Fabry-Pérot Interferometer,” N. Geis, R. Genzel, M. Haggerty, F. Herrmann, J. Jackson, S.C. Madden, T. Nikola, A. Poglitsch, M. Rumitz, G.J. Stacey, R. Timmermann, and C.H. Townes, in *Airborne Astronomy Symposium on the Galactic Ecosystem: From Gas to Stars to Dust*, M.R. Haas, J.A. Davidson, and E.F. Erickson (eds.), ASP **73**, 547 (1995).
- “A Search for Hydrogen Lasers in MWC 349 from the KAO,” V.S. Strel'nitski, H.A. Smith, M.R. Haas, S.W.J. Colgan, E.F. Erickson, N. Geis, D.J. Hollenbach, and C.H. Townes, in *Airborne Astronomy*

Symposium on the Galactic Ecosystem: From Gas to Stars to Dust, M.R. Haas, J.A. Davidson, and E.F. Erickson (eds.), ASP Conference Series 73, 271 (1995).

“The Galactic Nucleus: A Unique Region in the Galactic Ecosystem,” R. Genzel and A. Poglitsch, *Proc. “Airborne Astronomy Symposium on the Galactic Ecosystem: From Gas to Stars to Dust”* (San Francisco), M.R. Haas, J.A. Davidson, and E.F. Erickson (eds.), ASP 73, 447 (1995).

“A Multi-Wavelength Study of 30 Doradus: The Interstellar Medium in a Low-Metallicity Galaxy,” A. Poglitsch, R. Genzel, F. Herrmann, A. Krabbe, S.C. Madden, N. Geis, G.J. Stacey, C.H. Townes, and L.E. B. Johannsson, *“Airborne Astronomy Symposium on the Galactic Ecosystem: From Gas to Stars to Dust”* (San Francisco), M.R. Haas, J.A. Davidson, and E.F. Erickson (eds.), ASP 73, 141 (1995).

“Extragalactic Diffuse [CII] Emission,” S.C. Madden, N. Geis, C.H. Townes, R. Genzel, F. Herrmann, A. Poglitsch, and J. Stacey, *“Airborne Astronomy Symposium on the Galactic Ecosystem: From Gas to Stars to Dust”* (San Francisco), M.R. Haas, J.A. Davidson, and E.F. Erickson (eds.), ASP 73, 181 (1995).

1996

“Is there a compact central mass concentration in our galaxy?” C.H. Townes, *Unsolved Problems of the Milky Way*, L. Blitz and P. Teuben (eds.), p. 149-168, IAU (1996).

“Far-IR observations of the radio arc (thermal arches) in the Galactic Center,” R. Timmermann, R. Genzel, A. Poglitsch, D. Lutz, S. Madden, T. Nikola, N. Geis, and C.H. Townes. *ApJ* 466, 242 (1996).

“Atomic Oxygen in Molecular Clouds? High Resolution Spectroscopy of the [O1] 63 Micron Line Toward DR 21,” A. Poglitsch, F. Herrmann, R. Genzel, S.C. Madden, T. Nikola, and R. Timmermann, *Ap.J. Lett.* 462, L43 (1996).

“Atomic Oxygen in Molecular Clouds? Possible discovery of the $70\text{ }\mu\text{m H}_3\text{O}^+ 4^-_3 \rightarrow 3^+_3$ Transition in Orion BN-IRc2,” R. Timmermann, T. Nikola, A. Poglitsch, N. Geis, G. Stacey, and C.H. Townes. *ApJ Letts.* 463, L109 (1996).

“Far-Infrared Fine Structure Line Observations of the Galactic Center Radio Arc,” A. Poglitsch, R. Genzel, S.C. Madden, T. Nikola, R. Timmermann, N. Geis, and C. H. Townes, in “The Galactic Center,” R. Gredel (ed.), ASP Conference Series 102, 114-121 (1996).

“Airborne Observations of the 184 Micron $\text{H}_2^{18}\text{O } 2_{21} \rightarrow 2_{12}$ Transition in the Shocked Region of Orion BN-IRc2,” R. Timmermann, A. Poglitsch, T. Nikola, and N. Geis, *Ap.J. Lett.* 460, L65 (1996).

“C⁺ Emission from the Magellanic Clouds. I. The Bright HII Region Complexes N159 and N160,” F.P. Israel, P.R. Maloney, N. Geis, F. Herrmann, S.C. Madden, A. Poglitsch, and G.J. Stacey, *Ap.J.* 465, 738 (1996).

“Far-Infrared Observations of the Radio Arc (Thermal Arches) in the Galactic Center,” R. Timmermann, R. Genzel, A. Poglitsch, D. Lutz, S.C. Madden, T. Nikola, N. Geis, and C.H. Townes, *Ap.J.* **466**, 242 (1996).

To be published

“CO(1→0) Observations of molecular clouds in M83,” N. Geis, C.H. Townes, and J. Lugten. **In progress.**

“The Orion Molecular Cloud OMC1 and OMC2 mapped in the far-IR fine-structure line emission of C⁺ and O⁰,” F. Herrmann, S.C. Madden, T. Nikola, A. Poglitsch, R. Timmermann, N. Geis, and C.H. Townes. **Submitted to ApJ 1996.**
